EAN 2012
50th annual coference on experimental stress analysis

Non-destructive Tests of Modulus of Elasticity for the GLT Beams

Lenka Melzerová[1], Petr Kuklík [2]

Abstract: Twenty real dimensions beams from the glued laminated timber were tested in our previously works. Twenty advanced FE models were created precisely according to tested beams. Input files for FE models are lengths of segments and local moduli of elasticity. The segment is part of lamella between two finger joints. Each local modulus of elasticity was obtained via non-destructive penetration test. The output for comparison between real beam and FE model is displacement in half span. The quality of input data file from experiments is very important for the good agreement between real tested beams and FE models. In advanced FE models is described distribution of local moduli of elasticity via distribution function. The solution is based on the LHS. Accuracy of each distribution function is dependent on the number of measured local moduli of elasticity. In presented work is probabilistic approach for determination of corresponding number of penetration tests as function of segments lengths. Results of this analysis will be used in the latter series of bending tests of new real dimensions beams and corresponding advanced FE models.

Keywords: Non-destructive Tests; LHS method; Probabilistic Analyses

1. Introduction

The present contribution builds upon an extensive experimental program examining the behavior of glued laminated timber beams. Twenty beams were tested at the Department of steel and timber structures of the Faculty of Civil Engineering in Prague. Two types of experiments were conducted [1,2,4]. First, non-destructive measurements were performed to measure the elastic moduli of timber in the fiber direction at 1448 locations while monitoring the current state of moisture [6, 7]. The second type of experiments, performed on twenty beams, corresponds to destructive four-point bending tests with the option to measure various parameters with principal attention accorded to deflection at the center of beams.

The second part is then concerned with the finite element (FE) simulation of these experiments including the introduction of material uncertainty through variable Young's modulus. The first series of calculations assumes constant moduli assigned to individual segments as averages of values measured for a given segment. The numerical results show a relatively good agreement of this deterministic approach with experiments. The next part of the paper then deals with probabilistic

[1] *Ing. Lenka Melzerová, Ph.D.; Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29, Czech Republic; melzerov@fsv.cvut.cz*
[2] *Doc. Ing. Petr Kuklík, CSc.;Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29, Czech Republic;kuklik@fsv.cvut.cz*

simulations of the same beams assigning to each segment of the beam Young's modulus with a given probability of distribution. Individual samples (realizations), eventually providing the probability density function or the distribution function of the maximal deflection, were generated using the Latin Hypercube Sampling (LHS) method.

2. Probabilistic modeling using FEM

The advanced FEM models employ probabilistic simulations performed in the framework of LHS method. In the light of this, each segment is assigned Young's modulus with a corresponding probability density function [3]. In all cases the Gaussian distribution with the given mean and standard deviation is assumed as seen in Figure 1.

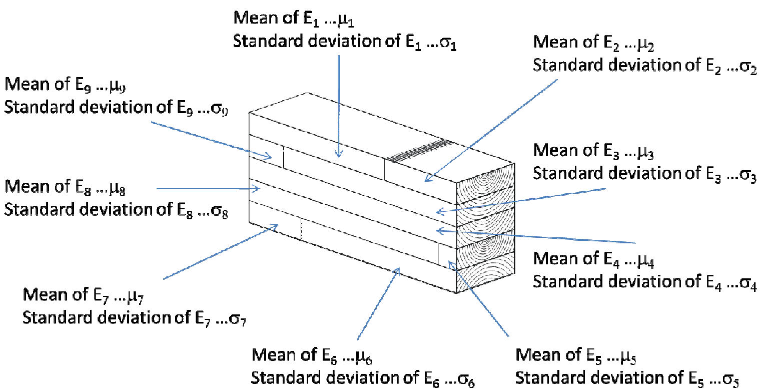

Fig. 1. Illustration of the input data used in the LHS method.

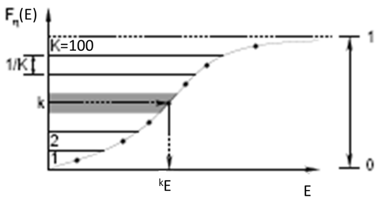

Fig. 2. Principle of selecting the k-th sample in the LHS method.

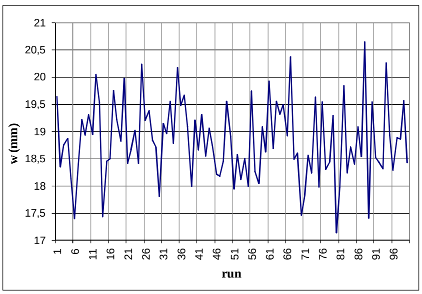

Fig. 3. Resulting maximal deflections for a single beam from one hundred realizations.

The associated distribution function is then utilized to generate individual samples. In the present study the distribution function was split into 100 intervals to randomly select a single value ${}^{k}E$ as schematically shown in Figure 2. This result is in accord with the LHS method based on 100 strata. The resulting map of realizations, see Table 1, is constructed such as to comply with a statistical independence of elastic moduli from segment to segment. Note that selecting lamellas to form a beam is conducted in a totally random manner.

Table 1. Example of creating individual realizations using the LHS method for a beam with 18 segments and 100 strata

	Beam for run 1	Beam for run 2	Beam for run 3	......	Beam for run 100
Segment 1	${}^{5}E_1$	${}^{90}E_1$	${}^{16}E_1$		${}^{4}E_1$
Segment 2	${}^{11}E_2$	${}^{7}E_2$	${}^{3}E_2$		${}^{92}E_2$
………..					
Segment 18	${}^{85}E_{18}$	${}^{1}E_{18}$	${}^{5}E_{18}$		${}^{10}E_{18}$

Figure 3 shows a variation of maximal deflections from 100 samples derived for a single beam with a given pattern of segments. These results can be statistically evaluated and fitted to the selected probability density function as illustrated in Figure 4 with the corresponding plot of the distribution function in Figure 5 for the Gaussian distribution.

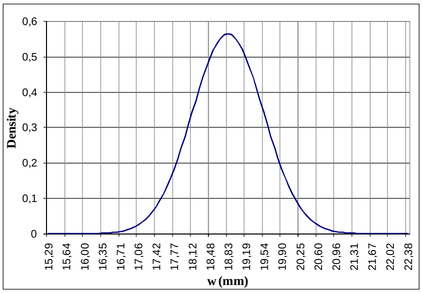

Fig. 4. Example of the Gaussian probability density function of deflection for the selected beam.

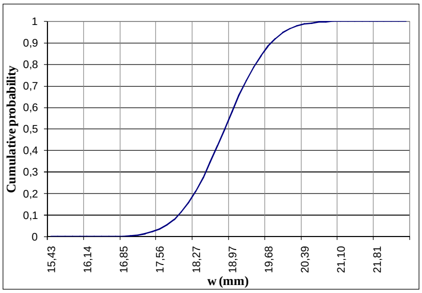

Fig. 5. Example of the Gaussian distribution function of deflection for the selected beam.

3. Comparing obtained results from FEM simulations and experiments and their evaluations

This section compares the results provided by individual methods. Henceforth, attention will be dedicated to the results provided by probabilistic simulations. To compare individual approaches (experiment, deterministic and probabilistic modeling) a single value given by the averages obtained from 100 samples, see also

Figures 4 and 5, will be adopted. This appears in Table 2 suggesting in such a case no need for more advanced and computationally exhausted probabilistic simulations. It might be, however, expected that a better agreement with experimental results will be obtained with improved probabilistic data of input parameters conditioned by considerably more measurements in individual segments (recall that only four measurements are presently available for each segment). Probability of not exceeding a certain limit deflection is even more important than a simple mean, although not examined, which might provide further insight in the behavior of such structures.

Table 2. Comparison of measured and numerically derived deflections for the selected beam

Material	*w(mm)*	*Percent of measured*
Measured	19.15	100
Discrete FEM	18.8	98.17
LHS	18.83	98.34

For the computational results the probability density function is re-plotted in Figure 6. The variations of maximal deflections in Figure 7 showing also the comparison with the averages delivered by the probabilistic analysis [5]. Clearly, when comparing only averages the difference between deterministic and probabilistic modeling is almost negligible. Recall, however, that above each mean value one should image a particular distribution, $f_{W,n}(w)$, as also schematically shown in Figure 7.

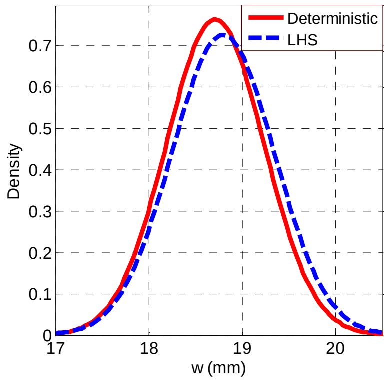

Fig. 6. Comparison of Gaussian probability density functions of calculated deflections from the ensemble provided by all 20 beams.

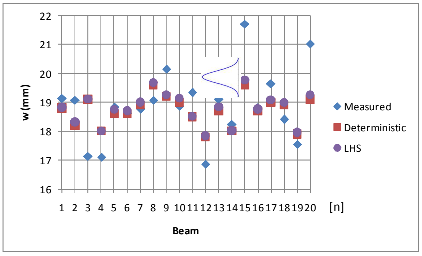

Fig. 7. Comparison of measured and calculated deflections (the circles show averages from 100 realizations obtained for individual beams).

This alows us to estimate the probability of exceeding a certain level of the assumed allowable deflection of the beam $\overline{w}$ as

$$P(w > \overline{w}) = 1 - \frac{1}{N} \sum_{n=1}^{N} F_{W,n}(w), \qquad (1)$$

where N is the number of beams and $F_{W,n}$ is the corresponding distribution function of the deflection of the n-th beam.

4. Conclusions

The presented results demonstrated that a certain improvement in the prediction of the response of glued timber beams can be achieved by extending the deterministic modeling to allow for a variability of input parameters in the framework of probabilistic simulation. However, the degree of improvement strongly depends on the quality of input parameters being in turn dependent on the number of available laboratory measurements. The actual computational methodology is nevertheless independent of such data. Also, it is not surprising that the results from the two approaches are rather similar since compared on the basis of averages only. Information provided by the stochastic analysis is, however, significantly broader, recall Equation (1).

Acknowledgement

This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic, project No. LD12023 advanced methods for design, strengthening and evaluation of glued laminated timber.

References

[1] Melzerova L. and Kuklik P., "Variability of Strength for Beams from the Glued Laminated Timber," in *Proceedings of the 48th International Scientific Conference on Experimentalni Analyza Napeti 2010 Experimental Stress Analysis,* Smid P., Horvath P., Hrabovsky M., eds., Velke Losiny, Czech Republic, May 31-Jun 03, 2010 (Palacky University, Olomouc, Krizkovskeho 8, Olomouc, 771 47, Czech Republic, 2010), pp. 257-260. ISBN 978-80-244-2533-7.

[2] Melzerova L. and Kuklik P., "Statistical Research of Mechanical Properties of Glued Laminated Timber Beams," *Metallurgy*, vol. 49, no. 2, pp. 376-380. ISSN 0543-5846.

[3] Melzerova L., Kuklik P., Šejnoha M., "Variable Local Modulus of Elasticity as Inputs to the FEM Models of Beams from the Glued Laminated Timber," in *2nd International Conference on Material Modelling.* Paris: TRANSVALOR-Presses des MINES, 2011, p. 313. ISBN 978-2-911256-61-5.

[4] Kuklík P., Melzerová L., *Kompozitní materiály na bázi dřeva* (České vysoké učení technické v Praze, Praha, 2011). ISBN 978-80-01-04958-7.

[5] Špačková O., Janda T., Novotná E., Šejnoha M., Jarušková D., Šejnoha J., *Computational Models for Tunnel Risk Assessment* (České vysoké učení technické v Praze, Praha, 2011). ISBN 978-80-01-04897-9.

[6] Plachy T, Tesarek P, Wilczynska A and Padevet P., "Experiment in Real Conditions: Mechanical Properties of Gypsum Block Determined Using Non-destructive and Destructive Methods," in *Proceedings of the 3rd WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology/International Conference on Geography and Geology* Martin O., Zheng X., eds., Corfu Island, Greece, Jul 22-24,

2010 (World Scientific And Engineering Acad And Soc, Ag Loannou Theologou 17-23, 15773 Zographou, Athens, Greece, 2010), pp. 418-423. ISBN 978-960-474-203-5.

[7] Plachy T., Tesarek P., Toupek R. and Polak M., “Nondestructive Determination of Young's Modulus of Gypsum Specimens Using Impulse Excitation Method,” in *Proceedings of the 48th International Scientific Conference on Experimentalni Analyza Napeti 2010 Experimental Stress Analysis*, Smid P., Horvath P., Hrabovsky M., eds., Velke Losiny, Czech Republic, May 31-Jun 03, 2010 (Palacky University, Olomouc, Krizkovskeho 8, Olomouc, 771 47, Czech Republic, 2010), pp. 339-344. ISBN 978-80-244-2533-7.